Abstract

Error characteristics associated with satellite-derived precipitation products are important for atmospheric and hydrological model data assimilation, forecasting, and climate diagnostic applications. This information also aids in the refinement of physical assumptions within algorithms by identifying geographical regions and seasons where existing algorithm physics may be incorrect or incomplete. Examination of relative errors between independent estimates derived from satellite microwave data is particularly important over regions with limited surface-based equipments for measuring rain rate such as the global oceans and tropical continents. In this context, analysis of microwave based satellite datasets from the Tropical Rainfall Measuring Mission (TRMM) enables to not only provide information regarding the inherent uncertainty within the current TRMM products, but also serves as an opportunity to prototype error characterization methodologies for the TRMM follow-on program, the Global Precipitation Measurement (GPM) .

Most of the TRMM uncertainty evaluation studies focus on the accuracy of rainfall accumulated over time (e.g., season/year). Evaluation of instantaneous rainfall intensities from TRMM orbital data products is relatively rare. These instantaneous products are known to potentially cause large uncertainties during real time flood forecasting studies at the watershed scale. This is more so over land regions, where the highly varying land surface emissivity offers a myriad of complications, hindering accurate rainfall estimation. The error components of orbital data products also tend to interact nonlinearly with hydrologic modeling uncertainty. Keeping these in mind, the present thesis fosters the development of uncertainty analysis using instantaneous satellite orbital data products (latest version 7 of

1B11, 2A25, 2A23, 2B31, 2A12) derived from the passive and active microwave sensors onboard TRMM satellite, namely TRMM Microwave Imager (TMI) and precipitation radar (PR). The study utilizes 11 years of orbital data from 2002 to 2012 over the Indian subcontinent and examines the influence of various error sources on the convective and stratiform precipitation types. Two approaches are taken up to examine uncertainty. While the first approach analyses independent contribution of error from these orbital data products, the second approach examines their combined effect. Based on the first approach, analysis conducted over the land regions of Mahanadi basin, India investigates three sources of uncertainty in detail. These include 1) errors due to improper delineation of rainfall signature within microwave footprint (rain/no rain classification), 2) uncertainty offered by the transfer function linking rainfall with TMI low frequency channels and 3) sampling errors owing to the narrow swath and infrequent visits of TRMM sensors. The second approach is hinged on evaluating the performance of rainfall estimates from each of these orbital data products by accumulating them within a spatial domain and using error decomposition methodologies.

Microwave radiometers have taken unprecedented satellite images of earth's weather, proving to be a valuable tool for quantitative estimation of precipitation from space. However, as mentioned earlier, with the widespread acceptance of microwave based precipitation products, it has also been recognized that they contain large uncertainties. One such source of uncertainty is contributed by improper detection of rainfall signature within radiometer footprints. To date, the most-advanced passive microwave retrieval algorithms make use of databases constructed by cloud or numerical weather model simulations that associate calculated microwave brightness temperature to physically plausible sample rain events. Delineation of rainfall signature from microwave footprints, also known as rain/no-rain classification (RNC) is an essential step without which the succeeding retrieval technique (using the database) gets corrupted easily. Although tremendous advances have been made to catapult RNC algorithms from simple empirical relations formulated for computational expedience to elaborate computer intensive schemes which effectively discriminate rainfall, a number of challenges remain to be addressed. Most of the algorithms that are globally developed for land, ocean and coastal regions may not perform well for regional catchments of small areal extent. Motivated by this fact, the present work develops a regional rainfall detection algorithm based on scattering index methodology for the land regions of study area. Performance evaluation of this algorithm, developed using low frequency channels (of 19 GHz, 22 GHz), are statistically tested for individual case study events during 2011 and 2012 Indian summer monsoonal months. Contingency table statistics and performance diagram show superior performance of the algorithm for land regions of the study region with accurate rain detection observed in 95% of the case studies. However, an important limitation of this approach is comparatively poor detection of low intensity stratiform rainfall.

The second source of uncertainty which is addressed by the present thesis, involves prediction of overland rainfall using TMI low frequency channels. Land, being a radiometrically warm and highly variable background, offers a myriad of complications for overland rain retrieval using microwave radiometer (like TMI). Hence, land rainfall algorithms of TRMM TMI have traditionally incorporated empirical relations of microwave brightness temperature (Tb) with rain rate, rather than relying on physically based radiative transfer modeling of rainfall (as implemented in TMI ocean algorithm). In the present study, sensitivity analysis is conducted using spearman rank correlation coefficient as the indicator, to estimate the best combination of TMI low frequency channels that are highly sensitive to near surface rainfall rate (NSR) from PR. Results indicate that, the TMI channel combinations not only contain information about rainfall wherein liquid water drops are the dominant hydrometeors, but also aids in surface noise reduction over a predominantly vegetative land surface background. Further, the variations of rainfall signature in these channel combinations were seldom assessed properly due to their inherent uncertainties and highly non linear relationship with rainfall. Copula theory is a powerful tool to characterize dependency between complex hydrological variables as well as aid in uncertainty modeling by ensemble generation. Hence, this work proposes a regional model using Archimedean copulas, to study dependency of TMI channel combinations with respect to precipitation, over the land regions of Mahanadi basin, India, using version 7 orbital data from TMI and PR. Studies conducted for different rainfall regimes over the study area show suitability of Clayton and Gumbel copula for modeling convective and stratiform rainfall types for majority of the intraseasonal months. Further, large ensembles of TMI Tb (from the highly sensitive TMI channel combination) were generated conditional on various quantiles (25^{th}, 50^{th}, 75^{th}, 95^{th}) of both convective and stratiform rainfall types. Comparatively greater ambiguity was observed in modeling extreme values of convective rain type. Finally, the efficiency of the proposed model was tested by comparing the results with traditionally employed linear and quadratic models. Results reveal superior performance of the proposed copula based technique.

Another persistent source of uncertainty inherent in low earth orbiting satellites like TRMM arise due to sampling errors of non negligible proportions owing to the narrow swath of satellite sensors coupled with a lack of continuous coverage due to infrequent satellite visits. This study investigates sampling uncertainty of seasonal rainfall estimates from PR, based on 11 years of PR 2A25 data product over the Indian subcontinent. A statistical bootstrap technique is employed to estimate the relative sampling errors using the PR data themselves. Results verify power law scaling characteristics of relative sampling errors with respect to space time scale of measurement. Sampling uncertainty estimates for mean seasonal rainfall was found to exhibit seasonal variations. To give a practical demonstration of the implications of bootstrap technique, PR relative sampling errors over the sub tropical river basin of Mahanadi, India were examined. Results revealed that bootstrap technique incurred relative sampling errors of <30% (for 2^0 grid), <35% (for 1^0 grid), <40% (for 0.5^0 grid) and <50% (for 0.25^0 grid). With respect to rainfall type, overall sampling uncertainty was found to be dominated by sampling uncertainty due to stratiform rainfall over the basin. In order to study the effect of sampling type on relative sampling uncertainty, the study compares the resulting error estimates with those obtained from latin hypercube sampling. Based on this study, it may be concluded that bootstrap approach can be successfully used for ascertaining relative sampling errors offered by TRMM-like satellites over gauged or ungauged basins lacking in in-situ validation data.

One of the important goals of TRMM Ground Validation Program has been to estimate the random and systematic uncertainty associated with TRMM rainfall estimates. Disentangling uncertainty in seasonal rainfall offered by independent observations of TMI and PR enables to identify errors and inconsistencies in the measurements by these instruments. Motivated by this thought, the present work examines the spatial error structure of daily precipitation derived from the version 7 TRMM instantaneous orbital data products through comparison with the APHRODITE data over a subtropical region namely Mahanadi river basin of the Indian subcontinent for the seasonal rainfall of 6 years from June 2002 to September 2007. The instantaneous products examined include TMI and PR data products of 2A12, 2A25 and 2B31 (combined data from PR and TMI). The spatial distribution of uncertainty from these data products was quantified based on the performance metrics derived from the contingency table. For the seasonal daily precipitation over 1^0x1^0 grids, the data product of 2A12 showed greater skill in detecting and quantifying the volume of rainfall when compared with 2A25 and 2B31 data products. Error characterization using various error models revealed that random errors from multiplicative error models were homoscedastic and that they better represented rainfall estimates from 2A12 algorithm. Error decomposition technique, performed to disentangle systematic and random errors, testified that the multiplicative error model representing rainfall from 2A12 algorithm, successfully estimated a greater percentage of systematic error than 2A25 or 2B31 algorithms. Results indicate that even though the radiometer derived 2A12 is known to suffer from many sources of uncertainties, spatial and temporal analysis over the case study region testifies that the 2A12 rainfall estimates are in a very good agreement with the reference estimates for the data period considered.

These findings clearly document that proper characterization of error structure offered by TMI and PR has wider implications in decision making, prior to incorporating the resulting orbital products for basin scale hydrologic modeling. The current missions of GPM envision a constellation of microwave sensors that can provide instantaneous products with a relatively negligible sampling error at daily or higher time scales. This study due to its simplicity and physical approach offers the ideal basis for future improvements in uncertainty modeling in precipitation.